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THE MANNED MANEUVERING UNIT FLIGHT CONTROLLER ARM

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ABSTRACT

The Manned Maneuvering Unit (MMU) and its support equipment provide an extravehicular astronaut mobility, and the ability to work outside the confines of the Shuttle Orbiter payload bay. The MMU design requirements are based on the highly successful Skylab M-509 maneuvering unit. Design of the MMU was started as an R&D effort in April 1975 and Flight Hardware design was started in August 1979 to support a possible requirement for in-space inspection and repair of Orbiter thermal protection tiles. Subsequently, the qualification test and production activities were slowed, and the current projected earliest first flight is now STS-11 in January, 1984.

The MMU propulsion subsystem provides complete redundancy with two identical "systems". Each system contains a high pressure gaseous nitrogen tank, an isolation valve, a regulator, and twelve 1.7 lbf (7.5 N) thrusters. The thrusters are packaged to provide the crew member six-degree-of-freedom control in response to commands from translational and rotational hand controllers. The MMU control and electrical subsystems are also redundant and provide thruster logic, power conditioning and distribution, and heater power. An automatic rate stabilization mode is also available for the three rotational axes. As the original program schedule was short, extensive use of "off-the-shelf" components and proven assembly techniques were used. Included with the MMU is its airborne support equipment, the Flight Support Station (FSS), that provides for the propulsion subsystem recharge capability and activation of separation nuts using gas from the Orbiter GN_2 environmental control system. All mechanisms have been designed and tested to ensure proper operation within astronaut applied force capabilities during and after exposure to severe acoustic and thermal environments. The most complicated of these mechanisms is the flight controller arm.

This paper discusses the MMU control arm requirements, design, and developmental history.

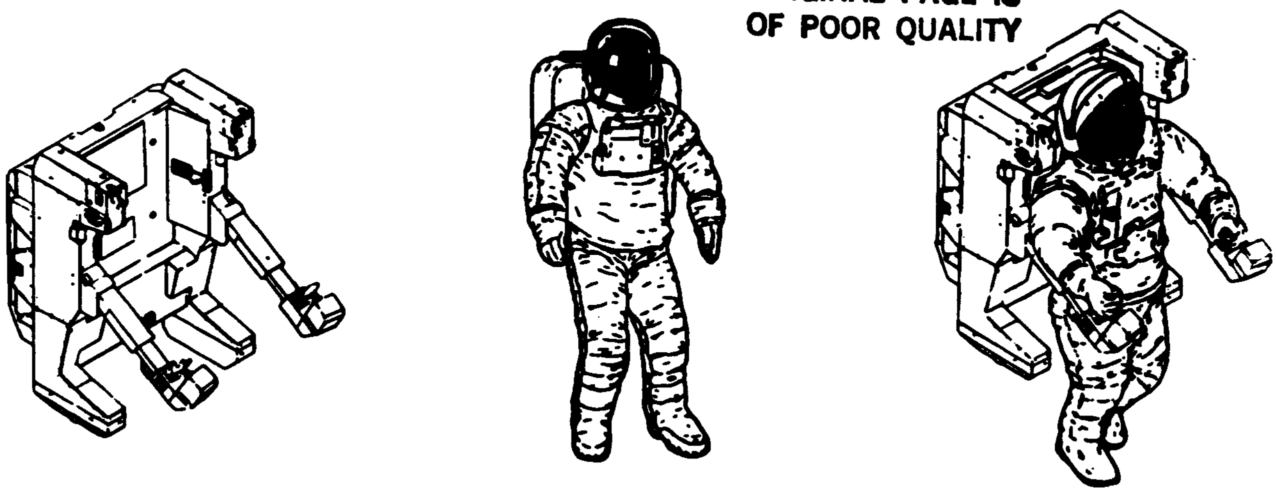
INTRODUCTION

The MMU is based on the M-509 maneuvering unit, flown inside the Orbital Work Shop for 14 hours by five astronauts on the two Skylab missions. Subsequent to the Skylab program Martin Marietta received a contract from NASA-Johnson Space Center (JSC) in April 1975, to perform technology surveys, conceptual design, preliminary definition, and design of an MMU for the Space Shuttle Program. Also included was the design, fabrication of prototype hand controllers, and high fidelity mockups of the MMU and FSS. Amendments to the contract resulted in the development of the control laws; design and breadboarding of the control electronics; design, fabrication, and testing of propulsion components such as the three thruster module (TRIAD), regulator, and isolation valve; and establishment of the interfaces of the MMU and FSS with the astronaut, Extravehicular Mobility Unit (EMU), and Orbiter. The development effort provided the sound technical base for the design and development of the MMU and FSS for Shuttle use.

Full scale development of the MMU started in August 1979 to support a Space Shuttle thermal protection tile inspection and repair mission under contract to JSC. The MMU can also support Space Shuttle operations involving payload inspection, servicing, and repair; aid in large structure construction; and perform emergency rescue. The MMU is a self-contained system consisting of power, control, propulsion, structure and mechanisms, and thermal subsystems designed for Astronaut Extravehicular Activity (EVA). Key features are shown in Figure 1. Electrical power is provided by redundant silver-zinc batteries with a normal output of 750 Wh at 16.8 Vdc. The control subsystem contains three major elements, two hand controllers and a Control Electronics Assembly (CEA). They operate together providing signals to the propulsion subsystem allowing rotational and translational motion. The CEA contains gyros for automatic attitude hold and circuitry to convert hand controller deflections to thruster valve commands. The MMU structure is assembled using aluminum frames and skin. Mechanisms are provided for: three arm positions and arm length adjustment of five in. (127mm) total to accommodate different size astronauts from a five percentile female, to a 95 percentile male; and attachment to the EMU primary life support system (PLSS). Thermal control is provided using white paint on the outside and heaters on selected components. The CEA heat is rejected by radiation from MMU aft panels that are covered with silverized teflon.

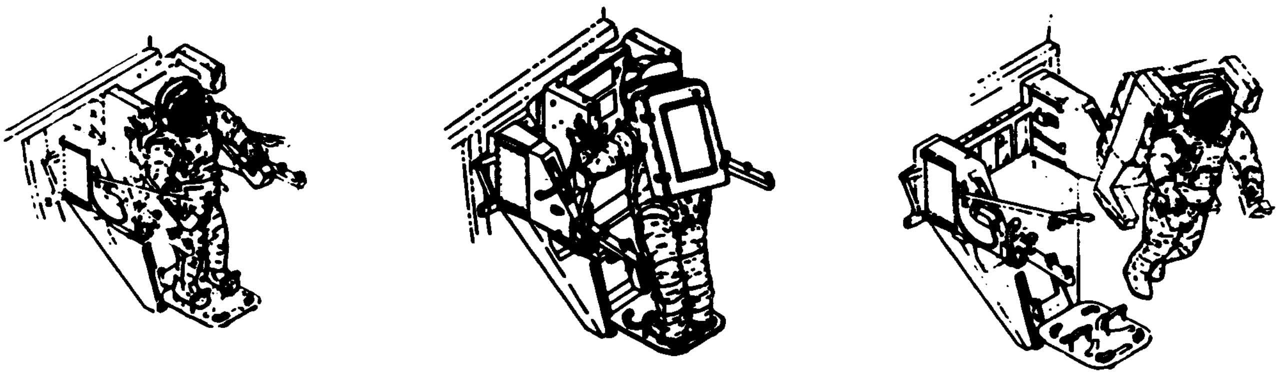
The Flight Support Station (FSS), shown in Figure 2, is a piece of air-borne support equipment which will be structurally attached to fittings in the Orbiter payload bay (Fig. 3). It provides for storage of the MMU when not in use; allows the astronaut to don and doff the MMU using handrails and adjustable foot restraints; provides an interface for and control of the Orbiter's GN_2 environment control supply gas for recharging of the MMU; and interfaces with the Orbiter's power and instrumentation system while providing heater power for the MMU and FSS.

The function of the MMU arm is to situate the hand controllers in a position where their operation can be achieved without discomfort to the suited crewmember.



(a) Manned Manuevering Unit (b) EMU and PLSS (c) MMU Latched to PLSS

Figure 1. Manned Manuevering Unit EVA System



Don/Doff Configuration Servicing Configuration Egress/Ingress

Figure 2. MMU Flight Support Station

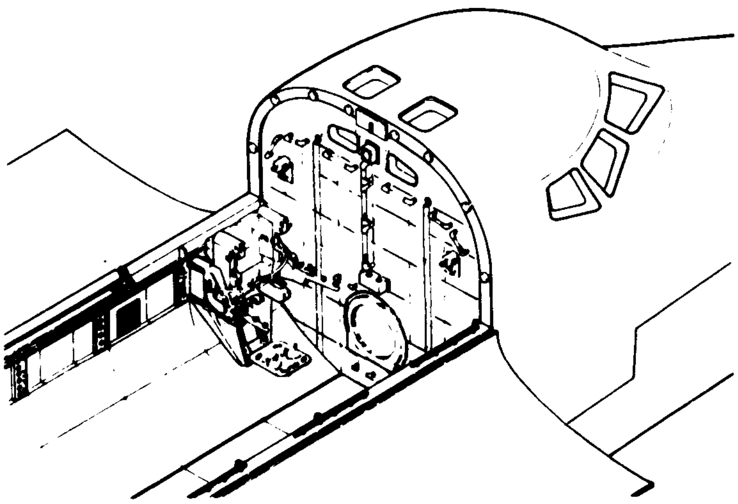


Figure 3. MMU Storage Location in Orbiter for Launch and Reentry

REQUIREMENTS

The basic requirement of the arm mechanisms design was that its three main mechanisms be prohibited from operating out of sequence.

The arm must be capable of being placed in three positions: "LAUNCH" the arm is fully folded back against the MMU body to permit the MMU to pass through the Orbiter airlock, and to withstand the space shuttle launch vibration environment; "WORK" is when the arm is positioned 82 deg below horizontal to allow the astronaut access to work at a worksite. "FLIGHT" the arm is positioned 30 deg below horizontal, positioning the hand controllers for comfortable operation.

When the crewmember operates the "LAUNCH" locks (See Fig 4) to release the arm from the "LAUNCH" position, the arms, when released, must automatically move into the "WORK" position, then be free to rotate to the "FLIGHT" position without operating additional latches.

In addition, to enable operation of the MMU by crewmembers in the size range from 5 percentile female to 95 percentile male, the arm length must be capable of being adjusted up to 5 in. in half inch increments. This requirement also necessitated that forces required to operate any mechanism be within the capability of the 5 percentile female.

It was also required that the arm be capable of operating in a temperature range of plus 150°F to minus 150°F. To cover the possibility of "LAUNCH" lock malfunction, it was required that a contingency arm release system be incorporated into the design.

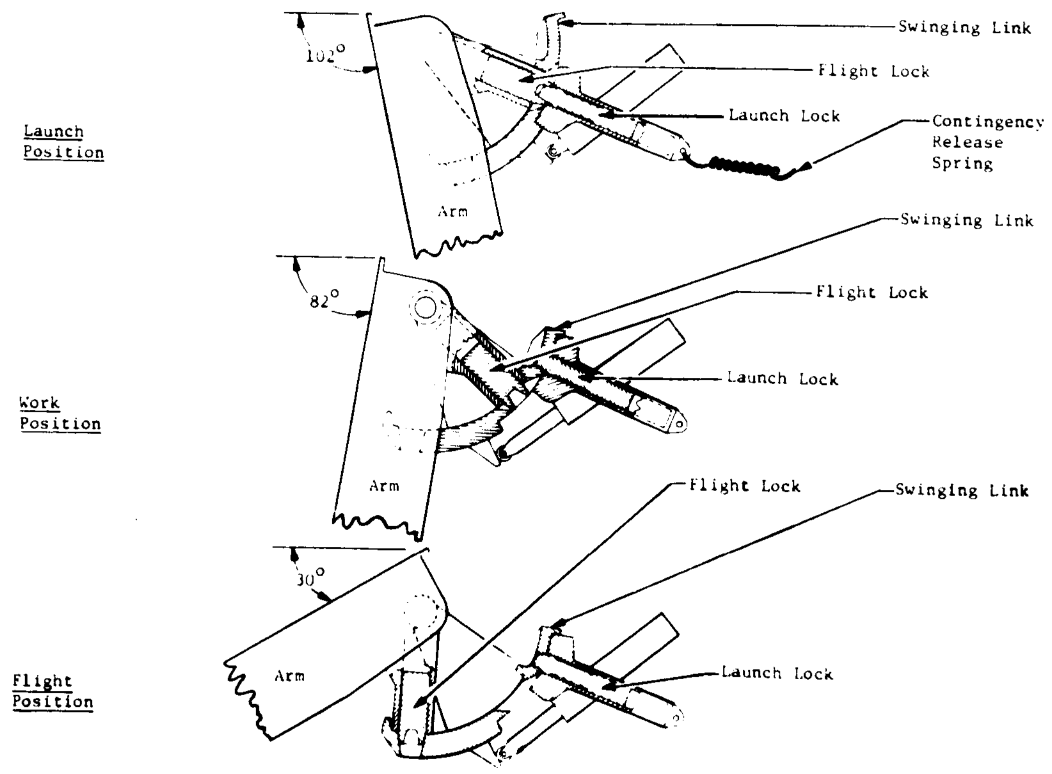


Figure 4. Swinging Link Operations

DESIGN

When the arm design was initiated a potential flight requirement for the MMU to support orbiter tile inspection and repair activities was nine months away. Flight hardware materials and hardware were in short supply at this time, causing delivery lead times that were difficult to meet. An attitude of designing with on-the-shelf hardware had to be adopted, sometimes causing such occurrences as machining simple bolts in small quantities.

The temperature requirements precluded the use of wet lubricants so that surface treatment dry lubricants had to be employed. To ensure there was no danger of cold weld within the moving parts of the mechanisms (assuming the dry lubricant had failed), the materials of any parts contacting while moving were very dissimilar, e.g., a CRES plunger in an aluminum housing.

An early design review demanded that all uses of snap-rings and other spring retaining devices be deleted from the design. This necessitated designing special hinge pin retention devices in very small sizes, having double locking features.

The external envelope of the arm had been determined by crew evaluation with early mockups. This cross section envelope consisted of a 3.75 in. wide by 2.00 in. rectangle. Priority had to be given in this space to two 0.7 in. dia wiring harnesses. Telescoping the arm to meet the arm length adjustment requirement further depleted the envelope, making the remaining space for latch mechanisms very constricted.

The requirement to preclude out of sequence operation of the mechanisms made for a formidable challenge. The worst of these was the requirement that when the flight latch is operated to let the arm down out of "FLIGHT" position, further operation of this latch could not permit the arm to travel beyond the "WORK" position. If the arm should travel past the "WORK" position with a suited astronaut locked into the MMU, his restricted reach might not permit him to reach the arm and return it to the "FLIGHT" position. To fulfill this design requirement, the part known as the "swinging link," which controls arm movement between the three required positions of the arm, was created (see Fig. 4).

The arm length adjustment requirement necessitated the use of some form of sliding action that was compact, easily moved, and prohibited excessive lateral or vertical movements between the arm sections. Cam follower roller bearings were selected. Unfortunately, the material from which commercial bearings are manufactured does not allow their use in temperatures as low as the arm requirements. Therefore, a roller design using approved materials was developed, employing dry lubricants without needles or balls.

When the arm length is adjusted, the length of the electrical harnesses has to adjust accordingly. The first design for the management of these harnesses assumed that it would be necessary for a tension load to be maintained on them to ensure they would retract into the MMU side tower when the arm length was reduced. When flight hardware was available for evaluation it was found that the harnesses were sufficiently stiff to enable them to be pushed without buckling, making the tension mechanism unnecessary. The present design provides a 180 deg loop in the harness which rolls back and forth inside the MMU side tower when the arm length is adjusted.

If the crewmember in preparation to don the MMU, finds he cannot release the arm from the launch position he has an alternative known as the arm release contingency plan. The launch lock housing is held into the hinge fitting by four special bolts with hexagonal heads which are flush with the MMU sidetower external skins. A dedicated MMU contingency tool is provided in the form of a ratchet drive socket. Using this tool the crewmember is able to remove the four bolts, which releases the launch lock assembly. This action is assisted by a tension spring attached to the launch lock which pulls the launch lock clear, freeing the arm for rotation to the flight position. To maintain the arm in the flight position holes in the side of the arm and the hinge fitting permit the insertion of a pip pin, thus enabling the MMU to still be flown.

The final arm design is a complicated mechanism designed to meet complicated requirements. Early in the design it was recognized that no matter how the parts were dimensioned, necessary tolerances would not permit guaranteed assembly. It was for this reason that peelable shims were introduced into the design and other modes of adjustment were employed where possible. Even so, assembly proved to be a lengthy, precise exercise using a build plan document which was very detailed in its step by step sequence. This assembly sequence was interrupted on several occasions by parts not going together as intended due to tolerance stackup. Due to the complexity it was not always possible to make a change in the most desirable manner without causing problems further on in the assembly.

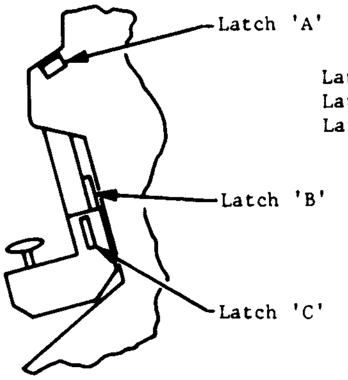
ANOMALIES

During crew training it was found that the arm could be locked into an unwanted fourth position. This problem was caused by the automatic push out device which kicks the arm from "LAUNCH" position to "WORK" position coupled with the crewmember tendency not to release the launch latch before the arm pendulum action tried to put the arm in a vertical position. This caused the launch latch to engage the launch position and the "flight" latch to engage the flight position, locking the arm in a position midway between "WORK" and "FLIGHT" positions. (See Figure 5.)

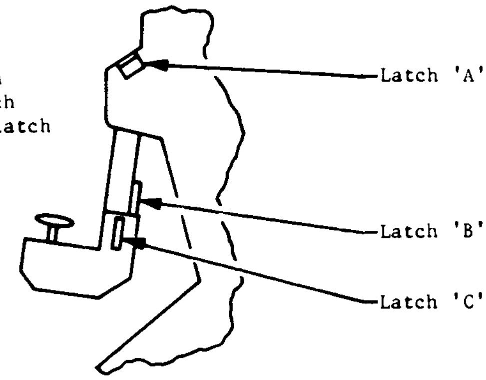
Changes were made to minimize the chances of engaging this position and, if engaged, make it easy to get out of.

The arm was cyclically tested to more than 1.5 lifetimes (3000 cycles). Posttest inspections found that the PTFE impregnated hard anodized material which had been used to provide lubricated surfaces on aluminum had shown very little signs of wear; however, this was not the case with the spray-on types of dry film lube working in line contact on stainless steel.

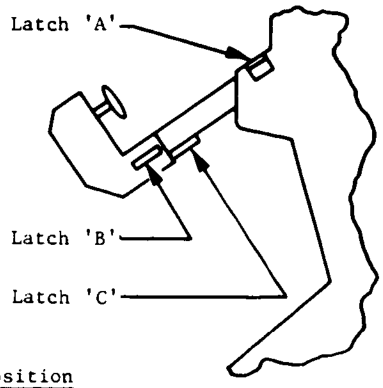
Latch 'A' 'LAUNCH'to 'WORK' latch
Latch 'B' 'WORK' to 'FLIGHT' latch
Latch 'C' Arm Length adjustment latch



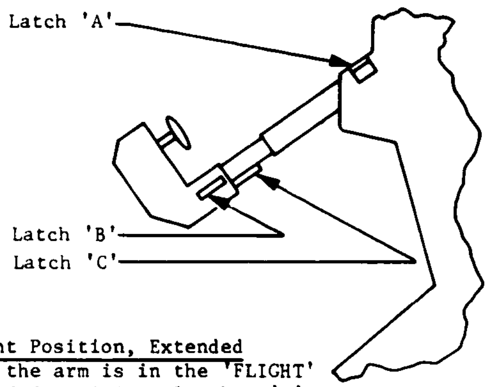
Launch Position
When the arm is in the 'LAUNCH' position, latches 'B' and 'C' are not operable. With the astronaut facing the MMU, actuation of latch 'A' releases the arm which automatically moves it into the 'WORK' position.



Work Position
When the arm is in 'WORK' position latch 'C' is not operable. With the astronaut locked into the MMU the arm is pulled up into 'FLIGHT' without the need to operate any latches; the arm will automatically lock into 'FLIGHT' position.



Flight Position
When the arm is in the 'FLIGHT' position latch 'A' is not operable. Latch 'C' is now free to allow arm to be extended to the desired length using aperture in top of arm to read indicator.



Flight Position, Extended
When the arm is in the 'FLIGHT' extended position, latches 'A' and 'B' are not operable. Note: It is only in the 'FLIGHT' position that the arm length can be adjusted.

Return to Flight Position
Operating latch 'C' allows arm to be retracted. Only when it is fully retracted does latch 'B' become operative. Latch 'A' is still not operable.

Return to Work Position
Operating latch 'B' allows the arm to be pushed down into 'WORK' position. Note:-If when in the work station, latch 'B' is operated, the arm cannot be pushed down toward the 'LAUNCH' position. Latch 'C' is again not operable. (To return to flight position again the arm when lifted automatically locks into 'FLIGHT' position).

Return to Launch Position
With the astronaut facing the MMU, operation of latch 'A' permits the arm to be pushed into 'LAUNCH' position, where it automatically locks. Again latches 'B' and 'C' are not operable.

Figure 5. Arm Operation

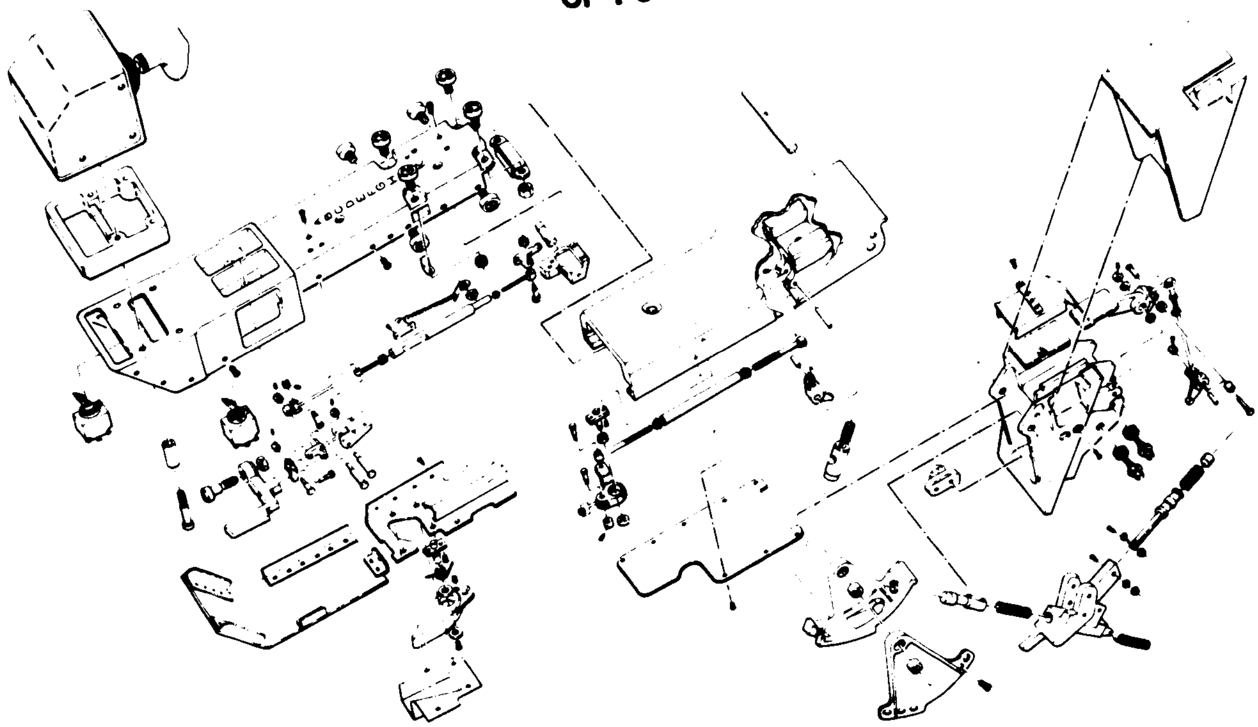


Figure 6. MMU Arm Exploded View

CONCLUSION

The final design consisted of approximately 150 machined parts, not including hardware and springs. (See Fig. 6.)

The arm has now successfully completed all functional, thermal, and vibration testing; and some of the flight hardware has been delivered to the customer.